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Abstract

Farmers have adopted biotechnology and genetically engineered (GE) crop technologies quickly. Yield data were analyzed from field experiments over the period 1990-2010 to test the hypothesis that GE corn technologies reduces production risk. GE technology can increase yield, but it also decreases yield for some GE traits. A significant part of the benefits of GE technology comes from protecting corn yield and reducing risk exposure. Gene interactions affect corn productivity through "yield lag" and "yield drag" effects. Often 3 to 4 years are required for new technologies to be equivalent to yields of conventional hybrids.

Introduction

Corn yield progress has increased dramatically over the last century. Average U.S. corn grain yields have increased from 119 to 153 bushels per acre between 1990 and 2010 (1). Over the last 15 years, biotechnology has been rapidly adopted in U.S. agriculture (2, 3). Quick adoption of genetically engineered (GE) corn by farmers indicates that farmers benefit from biotechnology. Yet, documenting the nature and sources of these benefits has been challenging (2, 3). By analyzing yield data from field experiments over the period 1990-2010 in Wisconsin, we show how transgenes affect corn yield, with a special focus on possible gene interactions and their effects on corn productivity.

The hypothesis is that GE crops can reduce production risk, as measured by the variance, skewness and kurtosis of corn yield in field evaluation trials. In general, reducing variance and increasing skewness are seen as desirable: it means a reduction in risk exposure (from a lower variance), and a decreased exposure to downside risk (from a higher skewness). Also decreasing kurtosis may be desirable to the extent that it means a lower exposure to rare events located in the tails of the yield distribution. In general, the mean, variance, skewness and kurtosis of yield vary with management choices, including GE genes that could lower yield loss and reduce risk exposure.

Materials and methods

The data used for the analysis is derived from field experiments conducted through the University of Wisconsin Corn Hybrid Performance Evaluation program from 1990 to 2010. The field experiments are conducted annually at 12-15 location across Wisconsin. Management practices were typical of those utilized on Corn Belt farms practicing rainfed agriculture. The seedbed at each location was usually prepared by fall plowing followed by spring roller harrowing. Fertilizer was applied as recommended by soil tests. Herbicides were applied for weed control and supplemented with cultivation when necessary. Insecticide was applied when the infestation level is above a certain level (that a typical farmer would find it economically reasonable to apply insecticides). Between two-row plots, twenty-five foot long, were planted at all locations. The experimental design was a randomized complete block where each hybrid was grown in at least three separate plots (replicates) at each location to account for field variability. Two-row plots were harvested with a self-propelled corn combine. Lodged plants and/or broken stalks were counted, plot grain weights, moisture content and test weight were measured and yields were calculated and adjusted to 15.5% moisture. A total of 4748 hybrids have been tested in the years analyzed, of which 2653 are conventional hybrids and 2095 are GE hybrids. Some hybrids are tested in multiple sites and/or for multiple years, yielding 31799 usable observations for the analysis.

The cost of risk is defined as the number of bushels of corn per acre a farmer is willing to give up to replace a risky yield with a mean yield. As such, it is expressed in bushels per acre. The cost of risk depends on the farmer's degree of risk aversion.

Results and discussion

The analysis showed strong evidence of gene interactions among GE traits when they are stacked. Both significant negative and positive interaction effects were found. While the identification of gene interactions in corn is not new (4, 5), the evidence of negative interaction effects among GE genes indicates that the performance of GE hybrids can be lower than conventional hybrids. Yet, such gene interactions are subject to management by geneticists and plant breeders (depending on where the GE genes are inserted in the germplasm as well as the quality of the germplasm used). It is a challenge to GE technology to manage such gene interactions in a productive way.

Lower performance may also be due to a time lag in the development of hybrids and the "rush to market" with GE gene technologies. These lags are measured by the number of years since the first introduction of a given event for each specific trait or system of traits (stacks). Such effects may develop if GE genes interact with the genetic material in the germplasm and where the GE genes are inserted in the germplasm, as well as the quality of the germplasm and success of the transfer of the GE gene(s). The analysis finds evidence of event lag effects, although such effects vary with each trait as well as their stacking. The effects of GE genes on corn yield in general depend upon the underlying germplasm. Plant breeders try to minimize over time any adverse interaction effects between GE genes and the germplasm. Yet, such gene interactions are found to vary with each GE gene.

GE hybrids were found to have significant effects on yield risk. First, GE technology affects the variance of corn yield (Table 1). These effects are in general negative (implying that GE hybrids lower yield variance), although they vary with the system of GE hybrids (e.g., with GE stacking). For the lag effects, the longer the GT and ECB single-trait events have been introduced, the lower the yield variance. However, the quadratic term time lag effect for ECB single-trait event is positive, suggesting that variance will eventually increase for that type of hybrid. This indicates that ECB does reduce yield variance in the short term, although such effects seem to decline in the longer term. The event lag effect on yield variance for the ECB and RW stacked event is also negative.

The estimation of the skewness and kurtosis of corn yield shows that GE traits do affect the distribution of corn yield (beyond their effects on variance). This indicates a need to go beyond mean-variance in the analysis of yield risk. In general, yield skewness is found to be negative, meaning that the yield distribution tends to be skewed to the left (implying a greater exposure to losses and downside risk). And yield kurtosis is found to be large: the "excess kurtosis" tends to be positive and statistically significant. This suggests that the distribution of corn yield has "fat tails". It means that the probability of rare events located in the tail of the distribution is higher than would be predicted from a normal distribution. Importantly, both GE and management are found to have significant effects on both skewness and kurtosis. Some of the GE effects are positive for skewness, indicating that GE hybrids contribute to reducing exposure to downside risk. And some of the GE effects are negative for kurtosis, showing that GE hybrids reduce the thickness of the tails of the corn yield distribution. These effects are somewhat complex as they vary with the system of GE traits (e.g., with GE stacking).

In general, the total cost of risk amounts to 2 to 4 percent of expected production (Table 2). While such percentages are not very large, they do provide useful information on the extent of risk exposure in corn production. First, most of the cost of risk comes from the variance component. For example, the total cost of risk for conventional hybrids is 6.36 bushels per acre; the variance component accounts for 90 percent of it (5.72 bushels per acre); and the skewness and kurtosis components account for about 5 percent each.

Table 1. Transgenic hybrid effects on risk. Grain yield or risk difference = transgenic – conventional.

Hybrid Type †	N	Mean yield (bu/A)		Variance		Skewness		Kurtosis	
Conventional	19,652	186	***	709	***	-5,770	***	794,000	***
ECB-Bt	3,484	6.54	***	-61	**	1,310		-280,000	***
CRW-Bt	36	-12.22	**	-72		9,840	*	-322,000	**
RR	972	-5.98	***	-151	***	2,690	*	-271,000	***
LL	103	5.76		-121		-5,540		221,000	
ECB, CRW	85	3.19		-460	***	4,440	**	-450,000	***
ECB, RR	1,454	3.47	***	-260	***	3,440	***	-411,000	***
CRW, RR	166	2.27		-242	***	3,820	***	-369,000	***
ECB, LL	998	3.13	**	-162	**	-3,090		-133,000	
ECB, CRW, RR	3215	-1.57	**	-336	***	3640	***	-433000	***
ECB, LL, RR	631	2.24		-147	**	2690		-279000	**
ECB, CRW, LL	206	2.04		-358	***	2740		-391000	***
ECB, CRW, LL, RR	797	-1.26		-258	***	2640		-365000	**

Statistical significance is noted by * at 10% level, ** at 5% level, and *** at 1% level.

† Conventional= Hybrids with no transgenic traits; ECB-Bt= European corn borer resistance trait; CRW-Bt= Corn rootworm resistance trait; RR= Glyphosate resistant trait; LL= Glufosinate resistant trait.

Table 2. Estimated risk cost for transgenic hybrids. Difference in total cost of risk (bu/A) = transgenic – conventional.

Hybrid Type †	Cost of risk due to variance	Cost of risk due to skewness	Cost of risk due to kurtosis	Total cost of risk	Difference in total cost of risk
Conventional	5.72	0.33	0.31	6.36	---
ECB-Bt	5.05	0.24	0.18	5.47	-0.89
CRW-Bt	5.50	-0.27	0.22	5.45	-0.91
RR	4.65	0.19	0.22	5.06	-1.30
LL	4.60	0.62	0.36	5.58	-0.78
ECB, CRW	1.97	0.07	0.13	2.17	-4.19
ECB, RR	3.56	0.13	0.14	3.83	-2.43
CRW, RR	3.72	0.11	0.16	3.99	-2.37
ECB, LL	4.34	0.50	0.24	5.08	-1.28
ECB, CRW, RR	3.03	0.13	0.14	3.30	-3.06
ECB, LL, RR	4.48	0.17	0.19	4.85	-1.51
ECB, CRW, LL	2.80	0.17	0.15	3.13	-3.23
ECB, CRW, LL, RR	3.66	0.18	0.17	4.01	-2.35

† Conventional= Hybrids with no transgenic traits; ECB-Bt= European corn borer resistance trait; CRW-Bt= Corn rootworm resistance trait; RR= Glyphosate resistant trait; LL= Glufosinate resistant trait.

All GE hybrids decrease the cost of risk compared to conventional hybrids. These effects come from reductions in all three components of risk: variance, skewness and kurtosis. The reduction in variance is found to be the dominant factor. But the reduction in downside risk (the skewness effect) and the reduction in the probability of facing rare events (the kurtosis effect) also contribute to reducing the cost of risk. This documents that GE hybrids do help reduce farmers' exposure to risk. However, these effects vary with the GE hybrids. In general, the stacking of traits within hybrids reduces risks further than the single-trait GE hybrids. This shows that multiple genes reinforce their effects on risk reduction, thus giving an advantage to stacked hybrids (compared to single-trait hybrids) in reducing risk.

What does all this mean for farmers? Buying corn hybrids is more confusing than ever. For years extension specialists have recommended to growers to choose hybrids by using comparative yield performance data. We do this by selecting hybrids with high average yield that is consistent across many environments and management situations. In the last few years these two basic principles have expanded to the following five principles:

1. Use multi-location averages to compare hybrids
2. Evaluate consistency of performance
3. Pay attention to seed costs
4. Every hybrid must stand on its own
5. Buy the traits you need

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